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## CONTROL OVER THE STEEL WELDING STRUCTURE PARAMETERS BY MICRO-JET COOLING

### STEROWANIE STRUKTURĄ STOPIWA Z WYKORZYSTANIEM CHŁODZENIA MIKROJETOWEGO PODCZAS SPAWANIA

The paper presents the characteristics of innovative technology of micro-jet cooling in MIG welding (according to PN-EN ISO 4063:2009). Presented results received at different jet hole geometry and various coolant pressure. This technology allows get, with appropriately selected parameters of cooling increased ferrite AF content in weld metal, up to 14% for standard MIG technology. This structure proves toughness, especially at temperature  $-40^{\circ}\text{C}$ .

*Keywords:* micro-jet cooling, weld, metallographic structure, acicular ferrite, impact toughness

W pracy scharakteryzowano innowacyjną technologię chłodzenia mikrojetowego podczas spawania metodą MIG (zgodnie z normą PN-EN ISO 4063:2009). Przedstawiono wyniki badań uzyskanych przy różnych ustawieniach geometrycznych otworów chłodzących oraz różnym ciśnieniu medium chłodzącego. Zastosowanie tej technologii pozwala uzyskać, przy odpowiednio dobranych parametrach chłodzenia większą zawartość ferrytu AF w stopiwie, do 14% w odniesieniu do standardowej technologii MIG. Ma to wpływ na udatność, szczególnie przy temperaturze  $-40^{\circ}\text{C}$ .

## 1. Introduction

To ensure the quality of welded joints must meet certain criteria. In most cases, these criteria relate to the value of weld strength, which ensure safety and durability in operation. To comply this criteria it is necessary to obtain adequate chemical composition and metallographic structure of the weld [1-4].

In the steel structure the best properties of weld strength are achieved with low-oxygen processes (approx. 400 ppm). That beneficial amount of AF in weld is connected with size, density and lattices parameters of oxide inclusion in weld. Having the most optimal inclusions in weld it is only possible to get at least 65% of AF in weld. The higher AF ferrite content the better the plastic properties of the weld. However, the application of actual welding technologies seems to be impossible to obtain higher content of ferrite AF in weld above 65% [2-5]. It was necessary to develop new technolo-

gy of weld cooling to maximize of ferrite AF content. Micro-jet technology gives chance to obtain artificially high amount of AF in weld that corresponds with better mechanical properties of weld. The micro-jet technology and injector parameters were used in the paper in order to analyze higher amount of AF (above 65%) and mechanical properties of weld [6, 7].

## 2. The weld metal cooling idea

This paper presents the results of a combined experimental in welding and other investigation focused on the effects of micro-jet cooling process. MIG welding technology (with micro-jet cooling) was only used in this work. Micro-jet technology allows for microstructure steering of weld. A diagram of the welding process with micro-jet accessory is shown in the Figure 1.

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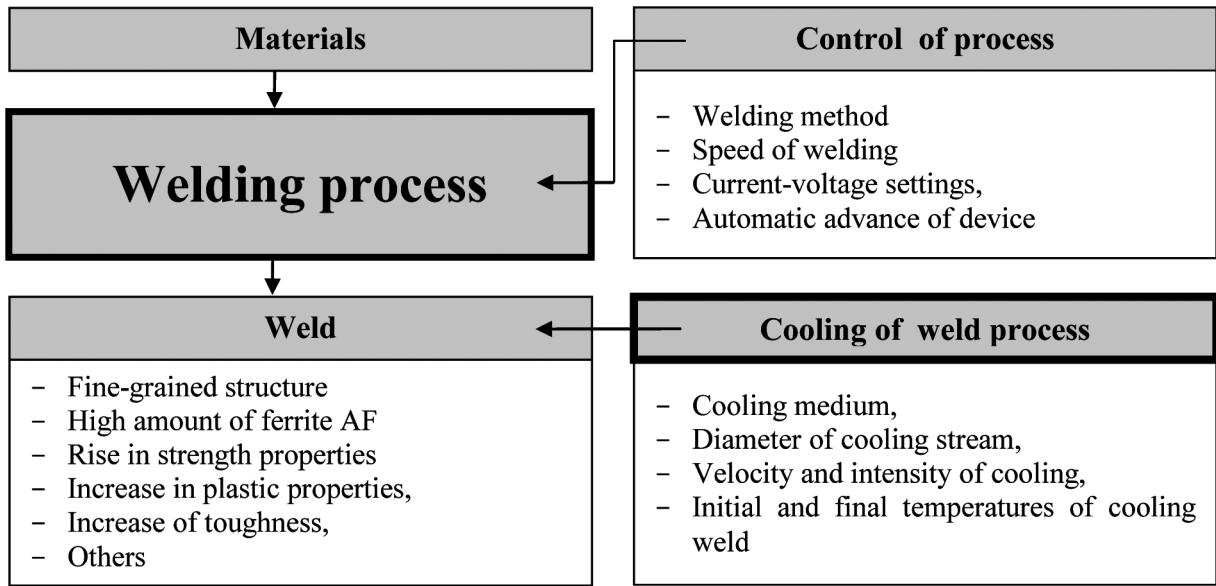


Fig. 1. A diagram of the welding process with weld metal cooling

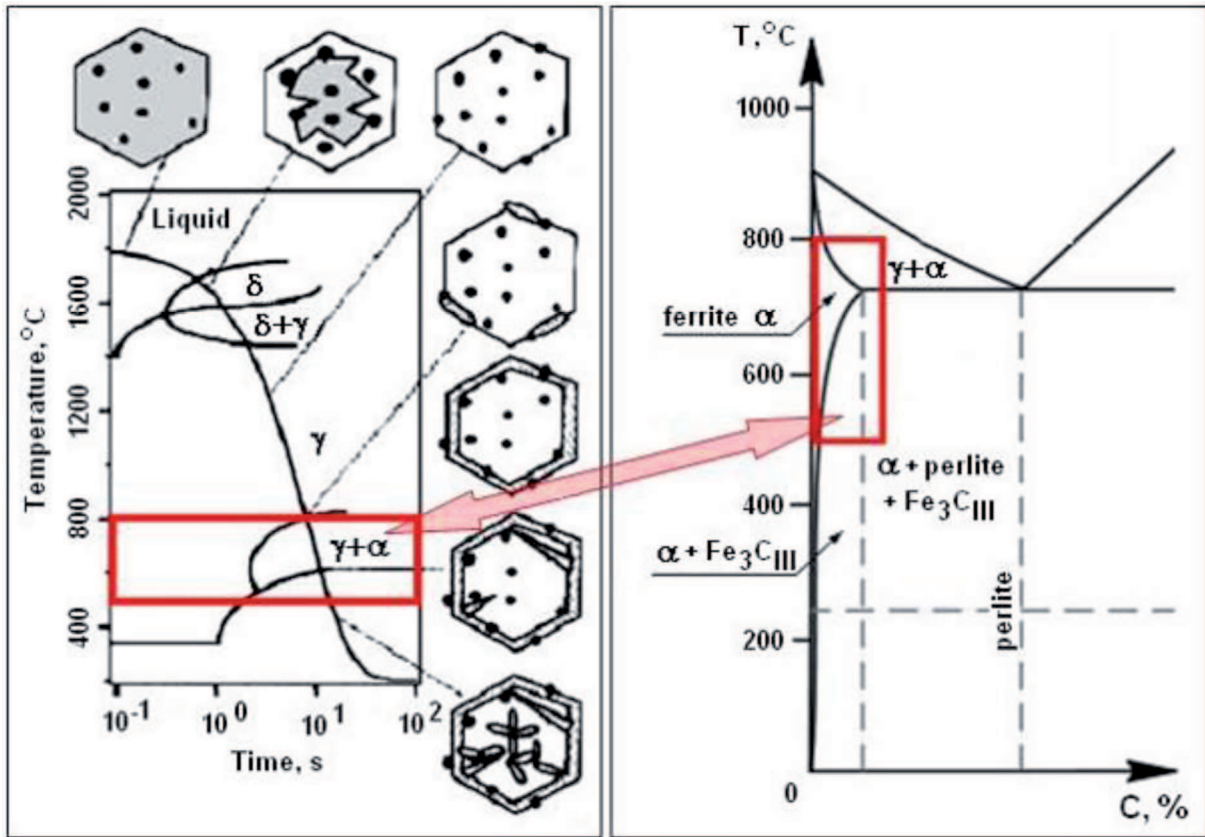


Fig. 2. Cooling TTT curve of weld metal deposit with reference to Fe-C diagram, areas where weld metal cooling is done are clearly marked

In this process, weld structure is under control because weld is respectively cooled by micro-streams of cooling medium (i.e. any liquid or gas). In that case, argon was chosen as cooling medium. Argon is chosen because of not oxidizing potential. Micro-streams of liquid are generated by micro-jet injector.

The micro-jet injector applications in welding process have been studied for low-alloy steel and low-carbon steel. The stages of formation of metallographic weld structure are listed below (Fig. 2):

- a) while continual cooling of austenite, coarse-grained ferrite is first formed on the grain boundary,

- b) next, plated ferrite is formed, it's superficial is oriented almost perpendicular to interior of the grains of "ex" austenite,
- c) finally, fine-grained ferrite is formed inside of the grains,
- d) at low temperatures, relatively a small quantity of austenite may be transformed into bainite and martensite,
- e) not large quantity of austenite may remain in metallographic structure (so-called remained austenite).

In Figure 2 are marked those areas where the process of weld metal cooling is done. It may be noticed that this process mainly takes place in the range temperatures of from 800°C to 500°C. The marked content of carbon in the weld metal results from the chemical content of additional material which was applied to welding [8-11].

The metallographic structure of the low-carbon and low-alloy weld metal consists mainly of three morphologic ferrite forms (Fig.2) [12-14]:

- coarse-grained ferrite marked as GBF (grain boundary ferrite),
- site plate ferrite, marked as PF (primary ferrite),
- fine-grained ferrite, marked as AF (acicular ferrite).

### 3. Experimental procedure

Weld metal deposit was prepared by welding with micro-jet cooling with varied geometrical parameters. The main data about parameters of welding were shown in Table 1.

TABLE 1  
Parameters of welding process

No.	Parameter	Value
1.	Principal diameter of wire	4 mm
2.	Standard current	220 A
3.	Voltage	24 V
4.	Shielding welding gas	Ar Ar + 1.5% O 82% Ar + 18% CO <sub>2</sub>
5.	Number of tested micro-jet cooling stream jets	1, 2, 3 (situated perpendicular and parallel spaced apart 4 mm, Fig. 4)
6.	Micro-jet welding shielded gas, gas pressure	Ar, 0.4 and 0.6 MPa

Only argon was chosen for micro-jet cooling (with diameter of 30 μm of stream). Cooling gas pressure was

0.4 and 0.6 MPa. There were tested welding conditions with installed micro-jet injector (Fig. 3). Cooling jets were situated perpendicular (X) and parallel (Y) to the direction of welding, spaced apart 4 mm. Equipment for MIG welding with micro-jet cooling and testing stand is presented in Figure 4.

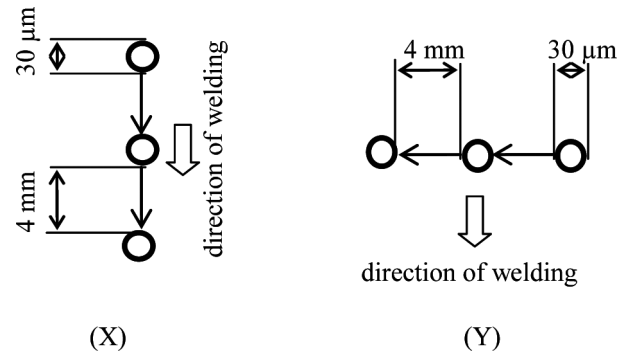


Fig. 3. Micro-jet cooling stream jets location

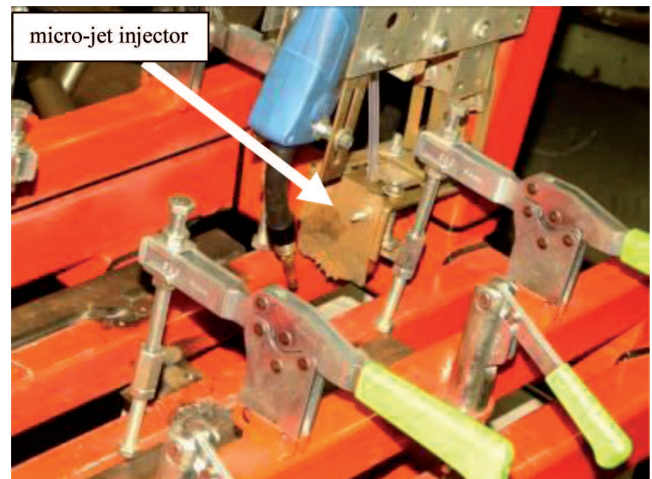


Fig. 4. Equipment for MIG welding with micro-jet injector

### 4. Results and discussion

The whole process of welding with micro-jet cooling take place with similar conditions: with perpendicular injector (X 0.4MPa and X 0.6 MPa), with parallel injectors (Y 0.4MPa and Y 0.6 MPa). Changes of micro-jet cooling parameter were not only of the geometry of the jets but also the gas pressure. The data presented in figure 5 are the average of the results of temperature at different parameters. For each parameter were carried out 5 times. The influence of additional weld cooling in range 800-500°C is precisely shown in Figure 5.

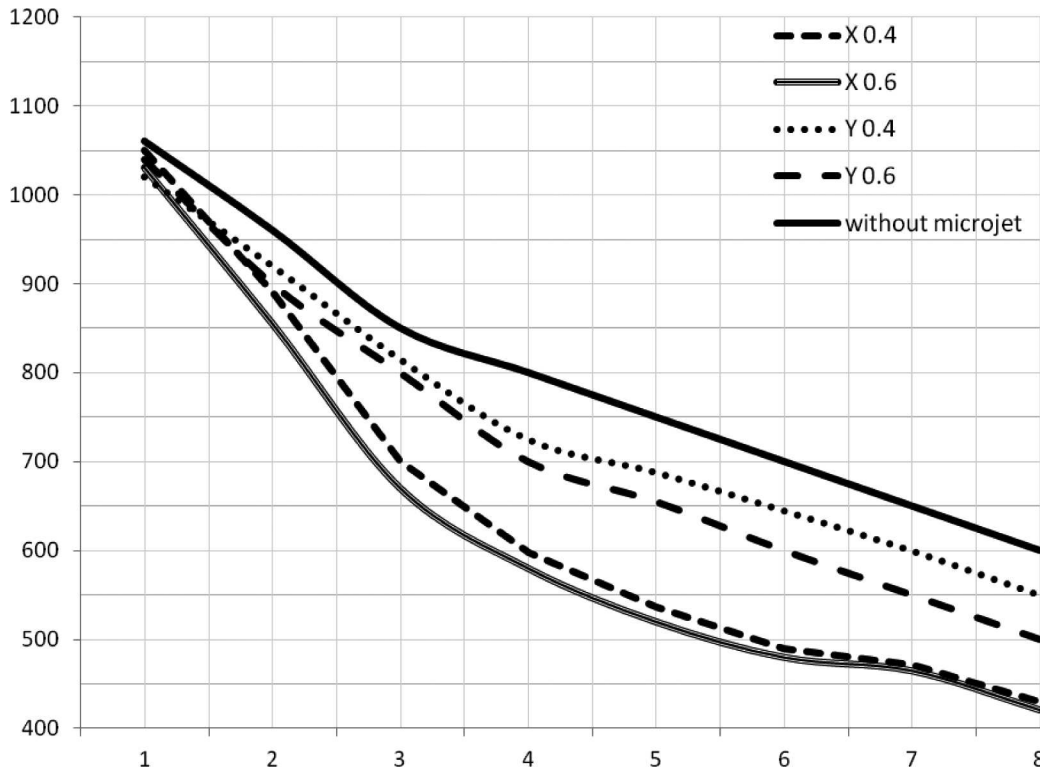


Fig. 5. Weld cooling conditions with micro-jet injector

The chemical composition was the same in all tested welds (Fig. 5). A typical weld metal deposit composition was shown in Table 2.

TABLE 2

A typical chemical composition of weld with micro-jet cooling

No.	Element	Amount
1.	C	0.08%
2.	Mn	0.79%
3.	Si	0.39%
4.	P	0.017%
5.	S	0.018%
6.	O	380 ppm
7.	N	85 ppm

There were typical analysed structures for MIG welding with micro-jet cooling. Example of this structure was shown on Figure 6.

The micro-jet cooling was designed to increase the amount of ferrite in the weld metal AF by reducing the ferrite GBF and SPF. The metallographic analysis confirmed earlier assumptions. All tested samples of weld metal with extra cooling demonstrated the increased amount of ferrite AF for standard MIG technology. It

should be noted that a significant impact on increasing the content of ferrite AF corresponds on injectors parameters. When cooling injector is in position X (as shown in Figure 3) and gas pressure was 0.4 and 0.6 MPa, cooling was too intensive for ferrite AF formation. Acicular ferrite increment was about 6% for the weld structure in standard technology. The largest increment, up to 14% of AF in weld was observed in weld metal after cooling injectors with setting Y (as shown in Figure 3) and gas pressure of 0.6 MPa. In this parameters weld metal was cooled together with base material that positively effects on the weld cooling. Gas pressure of 0.4 MPa at setting Y cooling injectors was too low and there was no significant increment of ferrite AF content in weld.

TABLE 3

Metallographic structure of weld

Parameters of micro-jet	Ferrite AF	MAC phases
—	56%	3%
X 0.4	65%	2%
X 0.6	64%	3%
Y 0.4	60%	3%
Y 0.6	69%	2%





Fig. 6. Example of typical analyzed structures for MIG: a) standard MIG; b) MIG with micro-jet (X 0.4); c) MIG with micro-jet (X 0.6); d) MIG with micro-jet (Y 0.4); e) MIG with micro-jet (Y 0.6). Magnification x 30

After that the chemical analysis, micrograph tests and Charpy V impact test on pendulum machine of the deposited metal were carried out. The Charpy V impact test was performed according to standard ISO 148-1 [14]. Samples for impact testing were prepared according to standard ASTM A370 [15].

Samples prior to testing in accordance with the standard [14, 15] were subjected to machining. The notch was made by milling. Used how to retrieve sections of sample and execution weighting had no impact on material properties. Due to the fact that the results obtained with impact notched bending samples are comparable only in the case tests of samples of identical size and shape notch and under the same conditions, and therefore all samples used in the tests were performed using the same tools. This is necessary because the dimension of the notch, and its shape significantly affect the acquisition values of toughness.

The way of preparation of samples for Charpy test was presented in Fig. 7 [15, 16]. Charpy V impact test was carried out in such a way that the hammer blow was to the middle notch, and the axis lying in the plane of movement of the hammer and the blade was directed to the supports.

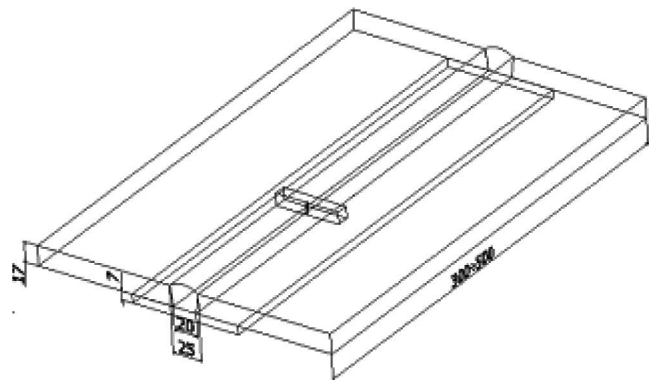


Fig. 7. The way of preparation of samples for Charpy test

The impact toughness results are given in table from 4. The Charpy tests were done mainly at temperature + 20°C, 0°C and – 40°C on 5 specimens having been extracted from each weld metal.

TABLE 4  
Impact toughness and amount of AF ferrite for welding with shielding gas Ar

Number of micro jets	Test temperature, °C	Impact toughness, J
X 0.4	- 40	50
X 0.6	- 40	51
Y 0.4	- 40	49
Y 0.6	- 40	54
X 0.4	0	66
X 0.6	0	65
Y 0.4	0	64
Y 0.6	0	67
X 0.4	+20	178
X 0.6	+20	180
Y 0.4	+20	176
Y 0.6	+20	179

The most beneficial influence of micro-jet cooling on the impact toughness values can be seen at the lowest tested temperature of -40°C (relative to the standard technology). Those results are higher by 4-7 J depending on the appropriate selection the cooling parameters. At temperatures 0 and 20°C there was not visible changes. This innovative technology is a very important one because it allows steering the structure and obtaining better mechanical properties of welds.

## 5. Summary and conclusions

On the basis of investigation it is possible to deduce that:

- micro-jet cooling could be treated as an important element of MIG welding process,
- high amount of ferrite AF can guarantee respectively good impact toughness properties.
- micro-jet cooling after welding can prove amount of ferrite AF, the most beneficial phase in low alloy steel weld metal deposit,

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